

TRAY SEDIMENTATION

WITH

SYPHON CONTROLS

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Abstract

This thesis presents the theory of sedimentation necessary for the design of a secondary clarifier, for applications where complete solids recycle is practiced. The development of tray clarification is briefly examined by looking at some of the problems encountered in past attempts of design. A design guideline is presented for a clarifier which utilized trayed levels to aid in sedimentation, and overcomes sludge removal problems of the past attempts at tray sedimentation, by using syphons to control flow. Solids are removed by flushing them from the trays. The design presented takes advantage of shallow settling depth, reduced overflow rate, reduced effect from outlet currents, and minimizes the effect of short-circuiting; and additionally, offers a means whereby future expansion may be made quite simply by rescheduling the operation.

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Tray Sedimentation

with

Syphon Controls

1. INTRODUCTION

In 1974, the city of Brandon, Manitoba, completed a project to alleviate their problem of insufficient winter storage in their sewage lagoons. The project involved the construction of an extended aeration treatment plant for winter operation. The secondary treatment thus provided allows the city to continually discharge the treated effluent to the Assiniboine River via the existing lagoons.

A novel design in the treatment plant is the secondary clarifier where clarification occurs in sedimentation channels that have three trayed levels. The idea of utilizing trays to aid in the sedimentation process is not new, although, earlier attempts by others were not very successful as practical problems were encountered with sludge removal (1,2)*.

1.1. Purpose and Scope

The original purpose of this paper was to evaluate the clarification system at Brandon, Manitoba. Due to operational problems within the treatment plant, the system did not provide a degree of treatment suitable for

* The numbers in parenthesis indicate references used in the text.

evaluation. The project was not abandoned since the novel design of the clarifier deserves further investigation. Some data of suspended solids concentrations are included as appendix B, although the reader should keep in mind that the results are not representative of the clarifier because an aerobic sludge floc did not develop.

The purpose of this paper is to present the design of tray sedimentation of wastewaters. Tray sedimentation with syphon controls utilizes a system of syphons to allow for a removal of collected solids from the clarification process and to control effluent draw-off. This paper attempts to compile the information on the design and to indicate important aspects of it. The design is directed mainly towards an application where complete recycle of settled solids is required.

2. SEDIMENTATION

Sedimentation is the removal of solid particles from suspension through gravity settling. The terms settling, sedimentation, clarification or thickening all refer to the removal of settleable solids, although clarification implies an interest in the quality of the clarified liquid; whereas, thickening implies an interest in the concentrated solids being collected (3).

The term tray sedimentation is derived from the fact that trays are incorporated to aid in the collection of settleable solids. In tray sedimentation the basic

fundamentals of settling are much more clearly evident than in the more conventional settling tank design used today. Hence, a review of the fundamental process of sedimentation is provided to allow the reader a better understanding of this paper.

2.1. Classification of Sedimentation

Sedimentation is a unit operation of sanitary engineering. In wastewater treatment, the unit operation of settling is used to remove: grit, organic particulate-matter in the primary settling basin, biological floc in the activated sludge settling basin, chemical floc from chemical coagulation and for solids concentration in sludge thickeners (4).

The settling of particles has been classified into four separate categories: type I - discrete, type II - flocculent, zone and compression settling (3,4,5). The classification for the type of settling is dependent on the concentration of the suspension and the character of the solids. It is common to have more than one category of settling taking place in one clarifier. In the sedimentation of raw domestic sewage, all four may be occurring simultaneously.

Type I settling refers to the sedimentation of discrete, nonflocculating particles in a dilute suspension (4). The solids settle with no interaction between neighbouring particles, e.g. a solution containing grains of

sand.

Type II settling refers to a dilute suspension of particles that flocculate or coalesce during sedimentation (4). Through flocculation or coalescing, the particles increase in mass and settle at a faster rate.

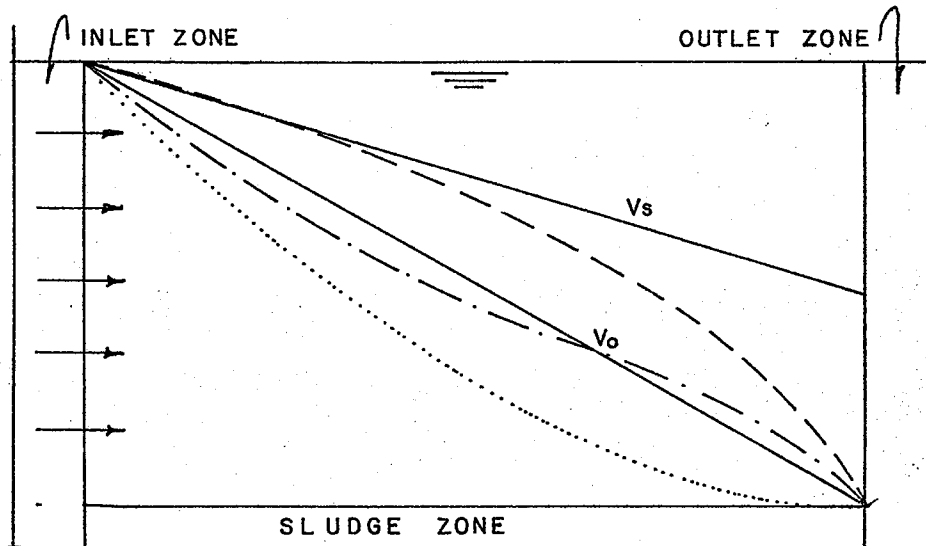
Zone settling refers to concentrated suspensions where interparticle forces are sufficient to cause a hindering of the settling. The particles settle in fixed positions with respect to each other and settle as a unit or zone (4).

Compression settling refers to the conditions which develop when the particles settling are of such concentration that a structure is formed. Further settling can only occur through compression of the structure (4). The compression is due to the weight of the particles being added on the top of the structure.

2.2. Type I - Discrete Settling

The settling of discrete, nonflocculating particles in a dilute suspension settle unhindered by the presence of other settling particles and is a function only of the properties of the fluid and particles in question (3).

The settling of a discrete particle can be described through the classical laws of mechanics. A list of the forces acting on a particle moving through a fluid are: the force due to gravity, the buoyant force due to the fluid, and the frictional or drag force. The resultant



- IDEAL, DISCRETE PARTICLE
- - - - - HINDERED ZONE
- FLOCCULENT
- · - · - MIXTURE, FLOCCULENT & HINDERED SETTLING

Figure 1: Discrete particle settling.

(Weber, J.W. Jr., Physicochemical Processes for Water Quality Control, Wiley-Interscience, New York, N.Y., 1972. p. 116)

force acting on any particle is then:

$$F_R = F_W - F_B - F_D \quad \dots\dots\dots (1)$$

where F_R = resultant force, lb. (force)
 F_W = force due to gravity, lb. (force)
 F_B = buoyant force, lb. (force)
 F_D = drag force, lb. (force)

The gravitational force may be calculated by (6):

$$F_W = \rho_s V_p g \quad \dots\dots\dots (2)$$

where ρ_s = particle density, lb. (mass) per cu. ft.
 V_p = particle volume, cu. ft.
 g = acceleration due to gravity, 32.17 ft. per sec.²

The buoyant force may be calculated by (6):

$$F_B = \rho_l V_p g \quad \dots\dots\dots (3)$$

where ρ_l = fluid density, lb. (mass) per cu. ft.

The drag force, a function of the size, roughness, shape and velocity of the particle and of the fluid density and viscosity have been found experimentally to be related as (3):

$$F_D = \frac{C_D A_p \rho_l v_s^2}{2} \quad \dots\dots\dots (4)$$

where C_D = Newton's dimensionless drag coefficient
 A_p = projected surface area of the particle in the direction of flow, sq. ft.
 v_s = the relative velocity between the particle and the fluid, ft. per sec.

The drag coefficient, C_D , has been experimentally demonstrated to be related to the Reynold's number, Re (3). The Reynold's number is a ratio of the inertia force per unit area to the viscous force per unit area (7). A relationship, considering spheres for particles, is that for Reynold's numbers between 1 and 10^4 , C_D can be approximated by (8),

$$C_D = \frac{24}{Re} + \frac{3}{\sqrt{Re}} + 0.34 \dots\dots\dots (5)$$

Particles other than spheres tend to have increased drag coefficients due to changes of shape (9).

Discrete particles settling under the influence of gravity continue to accelerate until the drag force is equal to the gravitational force. Considering a spherical particle:

$$\frac{3}{4} \frac{C_D \rho_l v_s^2}{\rho_s D_p} = g \frac{\rho_s - \rho_l}{\rho_s} \dots\dots\dots (6)$$

where D_p = particle diameter, ft.

When the acceleration of the particle becomes zero the settling velocity is constant. This velocity value is known as the terminal velocity u_t (3):

$$u_t = \left[\frac{4}{3} \frac{g}{C_D} \left(\frac{\rho_s - \rho_l}{\rho_l} \right) D_p \right]^{\frac{1}{2}} \dots\dots\dots (7)$$

where u_t = terminal settling velocity, ft. per sec.

Under normal conditions, generally the terminal velocity is quickly attained (3). If the terminal velocity of a suspension of discrete particles of uniform size and shape is known, the clarification rate can be easily computed (3):

$$q = \frac{Z}{t} A = u_t A \dots\dots\dots (8)$$

where q = volumetric rate of clarification, cu.ft./sec.

Z = distance through which particles settle in time t , ft.

t = time, sec.

A = cross-sectional area of a volume in a plane perpendicular to the direction of subsidence, sq. ft.

With reference to equation 8, all particles with a terminal velocity equal to or greater than u_t will be removed.

In sedimentation of discrete particles, the flow

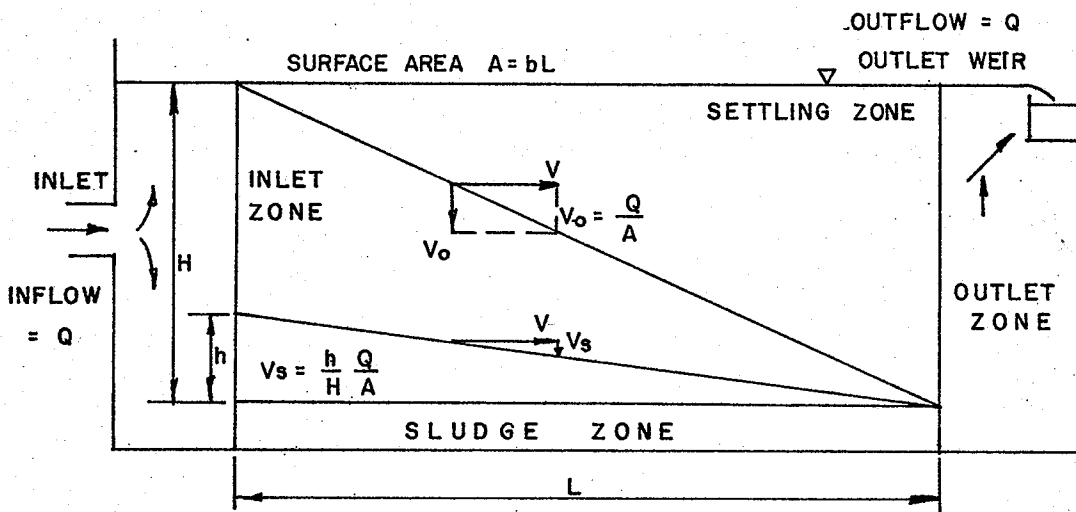


Figure 2: Sketch of an ideal rectangular sedimentation basin, indicating the settling of discrete particles.

(Clark, J.W., Viessman, W. Jr., Hammer, M.J., Water Supply and Pollution Control, second edition, International Textbook Co., Scranton, Ontario, 1971. p. 329)

capacity of the basin is theoretically independent of the basin depth and is a function only of the surface area for the basin and the settling velocity of the particle (3).

Discrete particles can be seen to settle at a constant velocity. The proportion of particles entering a settling tank that will be removed can be calculated from figure 2.

The depth of the tank is the product of the settling velocity and the retention time, t_0 (5).

$$\frac{h}{H} = \frac{v_s t_0}{v_0 t_0} = \frac{v_s}{v_0} \dots\dots\dots (9)$$

Hence, the proportion of particles of a given size that will be removed in a horizontal flow tank are (5):

$$\frac{v_s}{v_0} = \frac{v_s}{Q/A} \dots\dots\dots (10)$$

- where Q = rate of flow
- A = surface area of the settling zone, width x length
- v_s = settling velocity of the particle
- v_0 = settling velocity for 100% removal

Suppose the rectangular horizontal basin being discussed is altered to have an intermediate tray placed at the half-way depth. The velocity of the water in the tank has not been changed and the settling velocity of

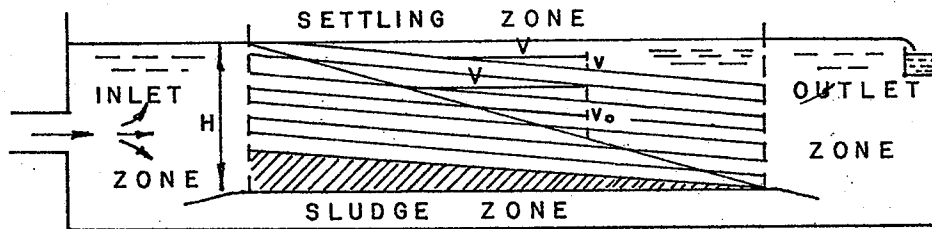


Figure 3: Zones of a rectangular, horizontal, continuous-flow sedimentation basin.

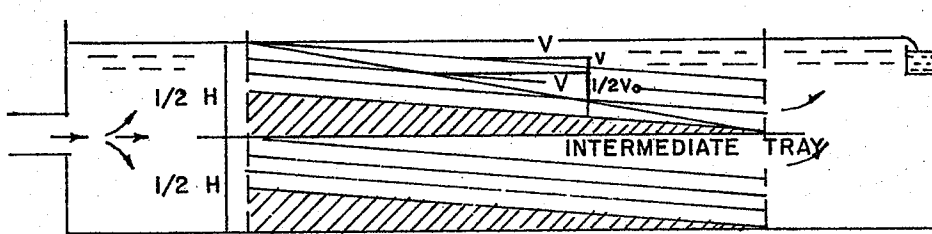


Figure 4: Tray in tank provides added floor area and increases solids removal.

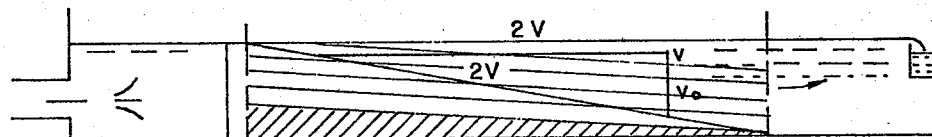


Figure 5: Reduced tank depth does not increase removal ratio.

(Camp, T.R., "Studies of Sedimentation Basin Design" Sewage Works Vol. 25, January 1953. Pp. 2,3.)

the particles remains the same. The depth through which the particles must settle is reduced by one-half and there is twice the floor area available to collect solids. The removal ratio has been doubled by the addition of the additional floor area (1).

If the idealized basin is constructed to only the half-way depth, the velocity of flow through the tank will be doubled, and all particles settling in this tank will have one-half the slope of corresponding paths for particles settling in the original settling basin. The removal ratio for the tank with twice the velocity and only half the depth is exactly the same as the original tank with the unaltered depth and velocity. It can be seen that the change in depth does not affect the removal ratio. Only changes in the surface or floor area and the settling velocity affect the removal ratio.

2.3. Type II - Flocculent Settling

The settling of particles, which are not discrete but will coalesce or flocculate during settling, have varying settling rates due to the increase in mass of the solids from flocculation. The degree of flocculation occurring is dependent on the overflow rate, the depth of the basin, the velocity gradients in the system, the concentration of particles, and the range of particle sizes (4). The overflow rate is "the unit volume of flow per unit of time divided by the unit tank area" (10). In effect it is the

average upflow velocity of the fluid through the settling solids.

The determination of the settling characteristics for a suspension of flocculent particles can only be obtained through a settling column analysis. The column may be of any reasonable diameter but the depth should be equal to or greater than the depth of the proposed design. A settling column analysis is conducted by allowing the suspension to settle under quiescent conditions. Samples are withdrawn at different time intervals at various depths and the concentration of particles is determined for each sample. The percent removals, of particles based on the original concentration, are calculated and plotted on a grid of depth versus time of settling. Isoconcentration lines connecting points of equal percent removal are drawn. These lines represent a "depth-time ratio equal to the minimum average settling velocity of the fraction of particles indicated" (3). The curvature of the lines represents the flocculating nature of the particles. Non-flocculating particles would plot as linear lines (3).

In conducting a settling column analysis, care must be exercised to ensure the original suspension is representative of the actual suspension being designed for, that a homogeneous mixture exists at the start of the test, and that the temperature of the suspension and the surrounding air are approximately equal (3,4). Temperature

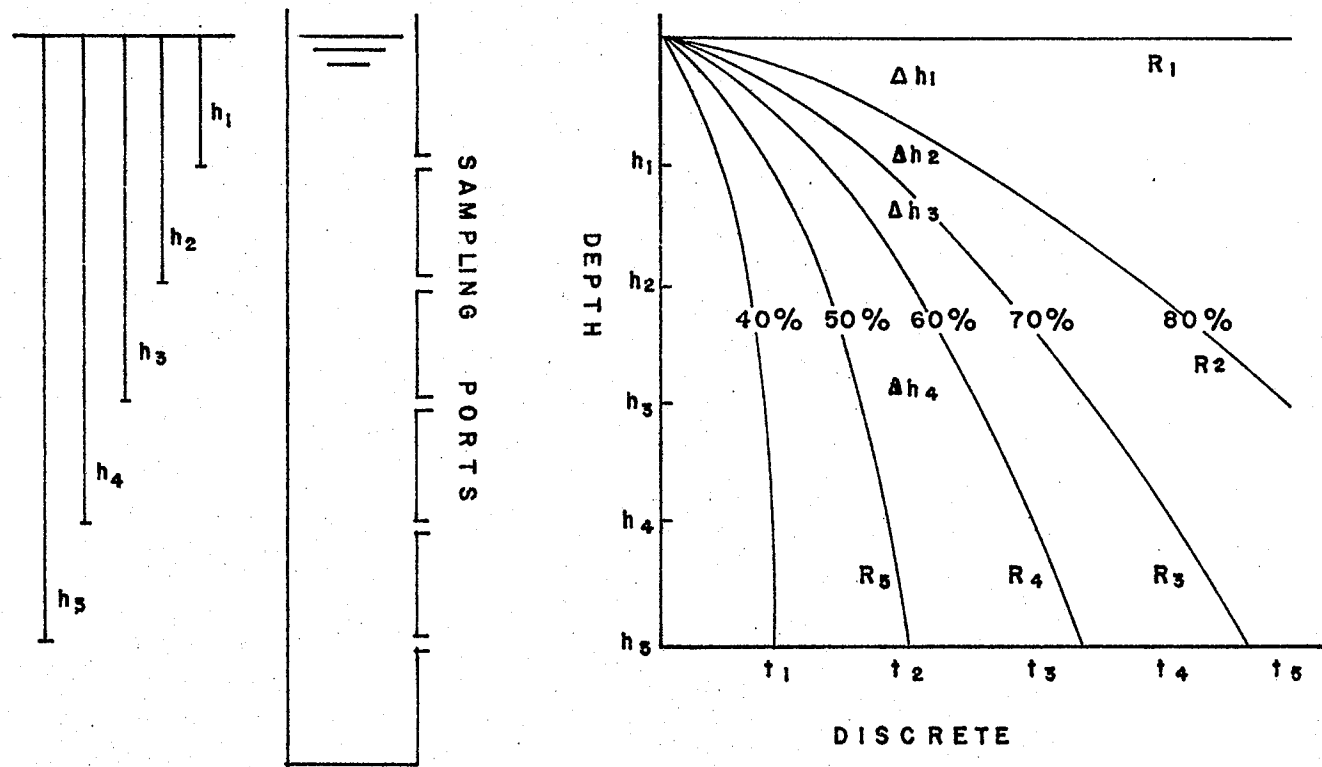


Figure 6: Quiescent settling column and settling curves for flocculent particles.

(Adapted from Metcalf and Eddy Inc., Wastewater Engineering: collection, treatment, disposal, McGraw-Hill Book Co., New York, N.Y., 1972. p. 289)

variations will develop convection currents which disrupt settling.

In figure 6, the percent removal of solids at time, t_2 , for a basin of depth, h_5 , at a clarification rate, q_0 , is determined from the plotted grid.

$$q_0 = \frac{h_5 A}{t_2} = u_{t_0} A \quad \dots\dots (11)$$

where $\frac{h_5}{t_2}$ = the average settling velocity of the particles during time, t_2 .

The overall percent removal, considering particles with settling velocities greater than $\frac{h_5}{t_2}$ can be calculated by (3):

$$\begin{aligned} \text{Overall Percent Removal} = & \frac{\Delta h_1}{h_5} \left(\frac{R_1 \times R_2}{2} \right) + \frac{\Delta h_2}{h_5} \left(\frac{R_2 \times R_3}{2} \right) \\ + & \frac{\Delta h_3}{h_5} \left(\frac{R_3 \times R_4}{2} \right) + \frac{\Delta h_4}{h_5} \left(\frac{R_4 \times R_5}{2} \right) \quad \dots\dots\dots (12) \end{aligned}$$

Metcalf and Eddy suggest that to achieve the desired removals indicated by settling tests, design settling velocities or overflow rate should be multiplied by a factor of 0.65 and that the detention times should be multiplied by a factor of 1.75 or 2.0 (4).

In clarification of particles which are of a

flocculent nature, the removal ratio is dependent on depth as well as the properties of the fluid and the particles.

2.4. Zone Settling

Zone settling occurs in solutions of concentrated suspensions where during settling the particles aggregate, forming a mass. The settling of the mass of particles is obstructed by the flow of upward displaced fluid and hindered settling occurs. The mass of particles settle as a blanket maintaining the same relative positions with respect to each other (4).

Distinct zones appear as the settling process proceeds. At the uppermost surface a clarified zone of clear water develops. Gradually, the clarified zone increases in depth and an individual particle settling zone develops beneath. The individual settling extends until the particles become hindered by the mass of solids below. A division, characterized by a water-solids interface, separates the individual particle settling zone from the hindered zone. The division appears as a "blanket" of solids. In the hindered zone, the particles settle at a reduced rate and no individual particle movement is observed (3). Eventually, the lower solids of the hindered zone begin to collect and collide with other particles already settled on the bottom of the basin. These colliding particles cause particles above to suffer a reduction in their downward settling velocity. This area of changing